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## Comment on "Four-body charge transfer processes in proton–helium collisions"

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We found, within the plane-wave first Born approximation (PWFB), that the proton-helium fully differential cross section (FDCS) for transfer excitation agrees well with the experimental one at the proton energy  $E_p = 300$  keV and small scattering angles both in shape and in magnitude. This result is in a contradiction with that obtained in [1].

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In Ref. [1], the authors consider the charge transfer with target excitation reaction (TTE)  $p+\text{He} \rightarrow \text{H}+\text{He}^{+*}$  at various proton energies and small scattering angles (few mrad). They calculated FDCS in comparison with the absolute experimental values [2]. In turn, the experimentalists claimed that they are able to resolve separately contributions from the ground and excited  $\text{He}^+$  states. The theorists used a specially developed 9D code for calculation of principal matrix elements. In such a way, they presented FBA (we call it PWFB to emphasize that both the proton and the hydrogen motion is described by plane waves in the center-of-mass reference frame) calculations of FDCS (see Fig. 4 in [1]). They found that a fitting factor of about  $v_p^4$  is necessary in order to compare theory and experiment.

The 9D integral, which describes the FBA matrix element for TTE in configurational space, can be reduced to a 3D one in momentum space, if plane waves are used for the proton and hydrogen center-of-mass motion and a trial helium wave function is of the configuration-interaction (CI) type. Results of such calculations are presented in Fig. 1. We take into account the following  $\text{He}^+$  excited states:  $2s, 2p, 3s, 3p, 3d$ . Three CI trial wave functions are used for the helium ground state: Roothaan-Hartree-Fock (RHF) [3] with a binding energy of -2.8617 a.u., Silverman-Platas-Matsen (SPM) [4] with a binding energy of -2.8952 a.u. and Mitroy [5] with a binding energy of -2.9031 a.u. The binding-energy value reflects a quality of the He wave function. We find practically ideal agreement between calculations using a well-correlated Mitroy wave function and experiment at small angles ( $\theta \leq 0.4$  mrad). For larger angles the agreement is less impressive, but in this particular case we expect a notable contribution from the second-Born term (we saw an analogous behavior for the  $1s - 1s$  transition [6]). We also find a splitting of the FDCS curves, which is characteristic of the TTE and TI reactions (see, for instance, [7]).

In Fig. 2, we present, for the sake of comparison, our calculations and those of Chowdhury and coworkers [1]. We include also the FDCS calculations with adding the leading  $1s$  state to the sum. We remark that contribution of excited states is about 5% of the  $1s - 1s$  transition, which is quite expected for  $E_p = 300$  keV.

In conclusion, we think that the 9D code requires a careful revision. We frequently encounter the effect that a choice of the integration scheme and computation grid strongly influences the results. Particularly it is relevant to calculations of tiny values against the background of large values. We wish every luck to the authors of the 9D code in overcoming the problems, as such a code is highly desired for various DWBA calculations of the capture and direct excitation/ionization processes induced by a heavy-projectile impact. In this case, we can test different distortion factors, as well as different target ground-state wave functions.

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## References

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- [1] Chowdhury U, Harris A L, Peacher J L and Madison D H, 2012 *J. Phys B: At. Mol. Opt. Phys.* **45** 035203
- [2] Schöffler M S, 2006 PhD Thesis University of Frankfurt am Main
- [3] Enrico Clementi and Carla Roetti, 1974 *Atomic Data and Nuclear Data Tables* **14** 177
- [4] Silverman J N, Platas O and Matsen F A, 1960 *J. Chem. Phys.* **32** 1402.
- [5] Mitroy J, McCarthy I E and Weigold E, 1985 *J. Phys. B: At. Mol. Phys.* **18** 4149
- [6] Hong-Keun Kim, Schöffler M S, Houamer S, Chuluunbaatar O, Titze J N, Schmidt L Ph H, Jahnke T, Schmidt-Böcking H, Galstyan A, Popov Yu V and Dörner R 2012 *Phys. Rev. A* **85** 022707.
- [7] Houamer S, Popov Yu V and Dal Cappello C 2010 *Phys. Rev. A* **81** 032703.

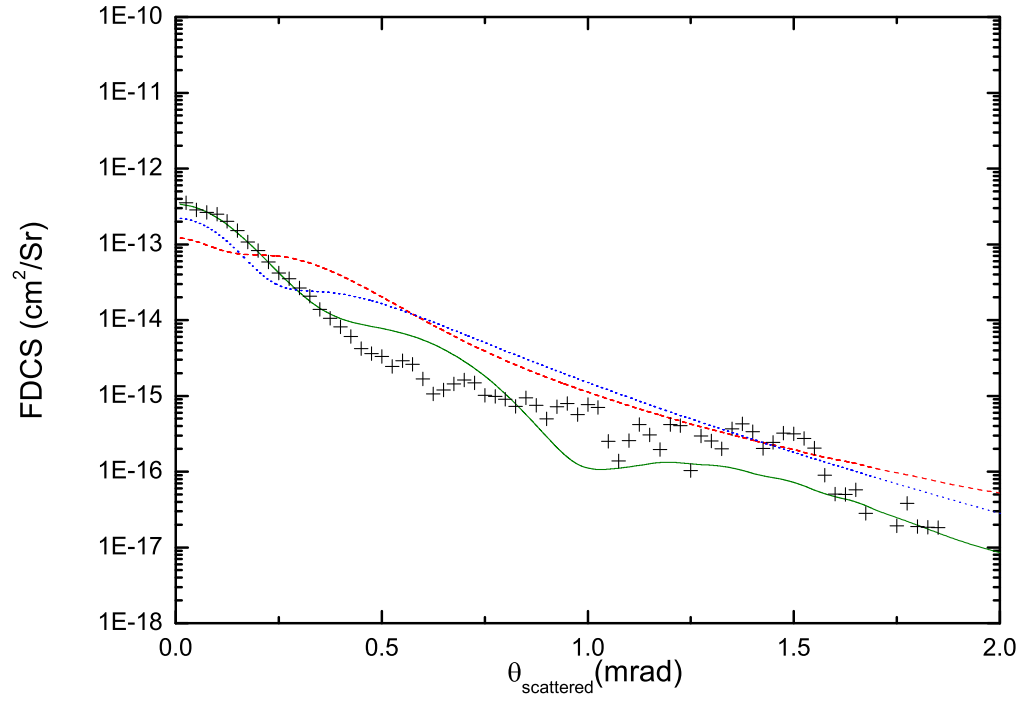


FIG. 1: FDCS as a function of the projectile scattering angle  $\theta$  in the lab system for three different target wave functions. Solid line (green) corresponds to Mitroy, dashed (red) to RHF, and dotted (blue) to SPM. Experimental values are due to Schöffler [2].

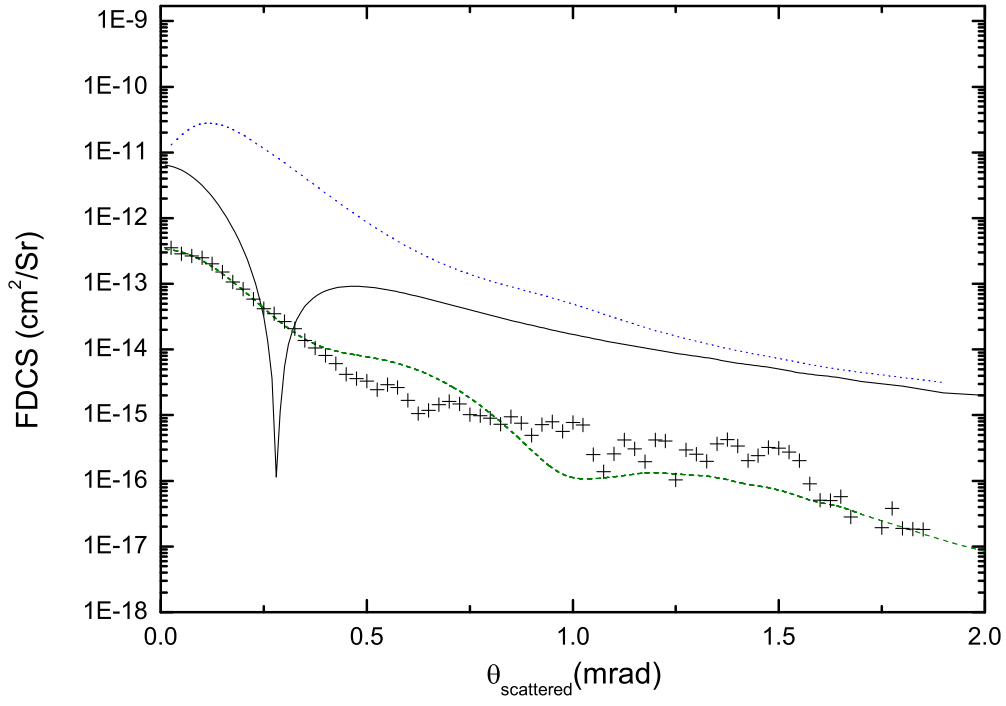


FIG. 2: FDCS as a function of the projectile scattering angle  $\theta$  in the lab system. Solid (black) line corresponds to inclusion of the  $1s$  state, dashed (green) to Mitroy for  $\text{He}^{+*}$ , and dotted (blue) to calculations from [1]. The experiment is due to Schöffler [2].